Risk and Sustainability: Assessing Resource Management Procedures

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Issue

- Sustainable management of fisheries under risk
  - Multi-criteria analysis (economic, ecological and social objectives)
  - Optimality vs. assessment of practical management procedures
  - Dealing with time (long-run and dynamics) and uncertainty

Charles (1998) Fisheries Research
Optimal fishery management under risk in the economic literature

- Economic literature:
  - Reed (1979) JEEM
  - Clark & Kirkwood (1986) JEEM
  - Danielsson (2002) JEEM
  - Sethi, Costello, Fisher, Hanemann (2005) JEEM
Economic approach

• The usual approach:
  - Stylized models
  - Optimal control with a unique economic criterion (discounted expected profit, harvest or utility)

\[
\max_{\{q_t\} \geq 0} \mathbb{E}\left\{ \sum_{t=0}^{\infty} \alpha_t h_t \right\}
\]

\[
\begin{align*}
  s_t &= x_t - h_t, \\
  m_t &= z^m_t x_t, \\
  h_t &= \min(x_t, z^i_t q_t)
\end{align*}
\]

The optimal feedback is hard to compute, and could hardly be applied in practice.
Literature (2/2)
Management Strategy Evaluation

- Fisheries management literature
  - Butterworth, Cochrane & De Oliveira (1997) ICES JMSc
  - Geromont, De Oliveira, et al. (1999) ICES JMSc
  - Saintsbury, Punt & Smith (2000) ICES JMSc
  - De Oliveira & Butterworth (2004) ICES JMSc
  - Fletcher (2005) ICES JMSc
  - Kell et al. (2005) ICES JMSc
  - Smith, Fulton et al. (2007) ICES JMSc
Fisheries Management Literature

• The MSE approach:
  - Realistic models; Simulation under uncertainty; Assessment of management procedures; Multicriteria analysis
  - Present the outcome of management procedures but do not rank them

Mean catches

+ MP1
- MP2

Risk of extinction for the resource

* MP1 is Pareto dominating MP2

MP1 is Pareto dominating MP2

Mean catches

+ MP1
- MP2

Risk of extinction for the resource

* MP1
* MP2
* MP3
Purpose of the paper

• To provide a theoretical framework to define optimal management strategies from a multi-criteria objective perspective
• To provide a practical framework to assess management procedures
• To describe the trade-offs between sustainability objectives in fisheries management, with environmental uncertainties
The stochastic viability approach

- Viability approach
  - Various sustainability objectives defined as viability constraints
  - Definition of viable decisions rules resulting in trajectories which satisfy all the constraints over time

- Viable Strategy Evaluation:
  - Viability probability: probability that there are viable decisions
  - MP that maximizes the viability probability
Viability literature

- Aubin (1991) Springer
Stochastic viability

- Formal model
  \[ x(t + 1) = G(t, x(t), u(t), \omega(t)) \]

- Decision rule
  \[ u(t) = \hat{u}(t, x) \in \mathbb{U} \]

- Uncertainty scenario
  \[ \Omega := \mathcal{W}^{T-t_0} \]
  as the set of scenarios, the notation\(^4\) for a scenario being
  \[ \omega(\cdot) := (\omega(t_0), \ldots, \omega(T-1)) \]

- Viability constraints: Indicators and thresholds
  \[ \mathcal{I}_k(t, x(t), u(t)) \geq \iota_k \]
Viability probability

- This is the probability over uncertainty scenarios that, given a decision rule and objectives, the resulting trajectory satisfying the constraints at all times.

\[ \Pi(\hat{u}, v_1, \ldots, v_K) := \mathbb{P} \left\{ \omega(\cdot) \in \Omega \right\} \]

\begin{align*}
& x(t_0) = x_0 \\
& x(t + 1) = G(t, x(t), u(t), \omega(t)) \\
& u(t) = \hat{u}(t, x(t)) \\
& I_k(t, x(t), u(t)) \geq \nu_k \\
& k = 1, \ldots, K \\
& t = t_0, \ldots, T
\end{align*}
The optimality case

• With “nice” models
  – “Monotonic dynamics”: increases with the stock and decreases with the effort
  – “Biological indicator”: increases with the stock and decreases with the effort
  – “Economic indicator”: increases with the effort and the stock
The optimality case

- With “nice” models
  - “Monotonic dynamics”: increases with the stock and decreases with the effort
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  - “Economic indicator”: increases with the effort and the stock

- Optimal management strategy, for given economic and ecological objectives, is a “precautionary management rule”:
  - Harvest only the quantity required to satisfy the economic viability constraint
The Bay of Biscay Hakes-Nephrops Fishery
(thanks to Claire Macher for the nice pictures)
Bioeconomic model for the viability analysis of the Bay of Biscay Hakes-Nephrops Fishery

- 2 species: Hake and Nephrops
- Uncertainty in recruitment
- Age-group dynamics
- 2 fleets: Hake and Nephrops
- Ecosystemic interactions:
  - The Nephrops fishery has an impact on the Hake fishery (juvenile hakes as bycatch)
- Economic indicator: Nephrops fishery's profit
- Ecological indicator: Recruitment in the Hake fishery (age group 4)
Results (1/2): Viability probability

Fig. 1: Viability probability for a range of sustainability objectives $\pi_{min}$ and $N_{min}^{h}$
Fig. 2: Sustainability objectives that are achievable with a probability greater than 0.9

Economic constraint: minimal profit

Ecological constraint: minimal recruitment
The sub-optimality case

- What can we do when it is not possible to define the management rule which maximizes the viability probability?

- We can compare given management strategies as in the Management Strategy Evaluation approach
  - Constant quotas
  - Constant effort
The Chilean Jack-Mackerel Fishery

- El Niño uncertainty impacts recruitment
- Age-structured model with Ricker recruitment function (w.r.t. SSB)
- Economic objective: Profit maximization
- Ecological objective: Stock preservation
Management Strategy Evaluation
Constant quotas vs. constant effort

VIABILITY PROBABILITY

Economic objective

Ecological objective

Economic objective

Ecological objective
Constant quota vs. Constant effort

Area of the most effective policy

Economical constraint

Biological constraint

constant quota
equality
constant fishing effort
unvielable area
Conclusion

- The stochastic viability approach
  - Provide of optimality and sub-optimality in a multicriteria framework
  - Makes it possible to rank MPs w.r.t. their viability probability

- Remark: Dimensional curse can be avoided by focusing on key interactions within exploited ecosystems (extension of single species indicator approach, as argued by A. Charles, 2005)
Thank you for your attention

• References:

  - De Lara & Martinet (2009) 'Multi-criteria dynamic decision under uncertainty: A stochastic viability analysis and an application to sustainable fishery management', Mathematical Biosciences 217:118-124


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